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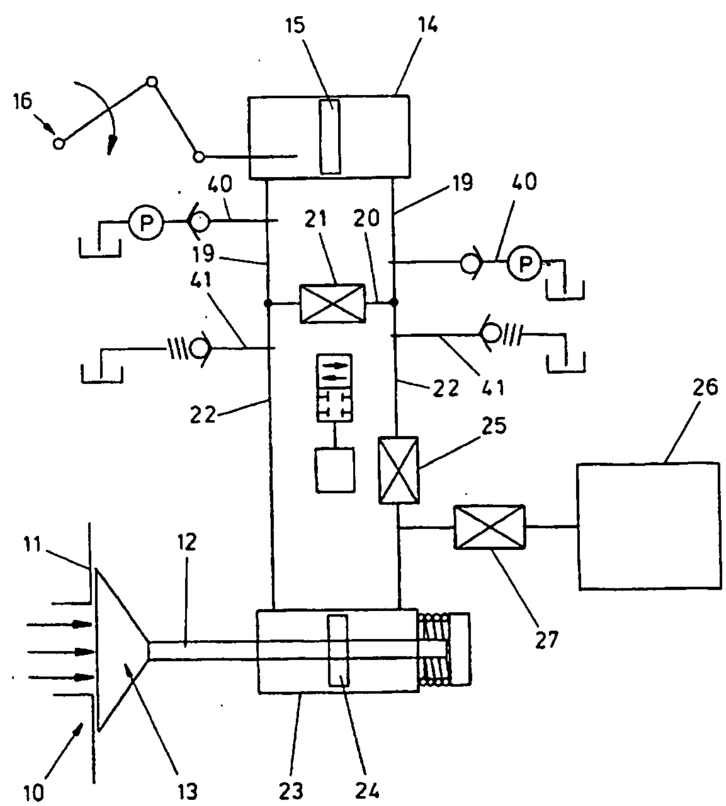
(54) Title: HYDRAULICALLY ACTUATED CYLINDER VALVE

(57) Abstract

A hydraulic actuator (10) which controls the operation of a cylinder valve having a valve seat (11), and a valve element (12) which is linearly reciprocable between open and closed positions with respect to valve seat (11), a valve seal housed in the closing face of valve head (13), (or a part of the valve seat (11) engaged by head (13)), a valve operator connected to the valve element (12) and operable in a release mode to move the valve element away from its valve seat and in a valve-closing mode to move the valve element towards its valve seat, and a hydraulic actuator circuit (19, 22) communicating with the valve operator and operable to apply a closing motion to the valve element (12) via the valve operator which reduces in speed as the valve element (12) moves towards the valve seat (11) and engages with the valve seal. The hydraulic actuator is particularly suitable for controlling the operation of a cylinder valve of a positive displacement type compressor having "soft" seals, although it does have general application to hydraulic actuation of cylinder valves of other types of engine having valve controlled fluid pressure chambers which are filled, pressurised and then discharge pressure fluid in repeated cycles of operation.



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HYDRAULICALLY ACTUATED CYLINDER VALVE

This invention relates, in one aspect, to a hydraulically actuated cylinder valve, and is particularly, though not exclusively concerned with the hydraulic actuation of inlet and exhaust valves of positive displacement type air compressors (linearly displaceable piston type air compressors). It should be understood, however, that the invention is not restricted to such use, and may be applied to the hydraulic actuation of other types of valve controlled pressure chambers which are filled with a fluid medium which is then pressurised, and exhausted, in repeated cycles of operation. Further, in another aspect, the invention is concerned with a linearly reciprocating piston type compressor which comprises a cylinder, a floating piston mounted for linear reciprocation in said cylinder, a piston rod coupled with said piston and guided so as to control the reciprocating movement of the piston in said cylinder so as to be substantially without direct metal to metal contact with the internal wall of the cylinder, at least one cylinder valve for controlling the admission, or exhaust of gas relative to the cylinder, a valve seat co-operable with said cylinder valve, and an improved actuator for controlling the operating movement of the cylinder valve.

Modern air compressors have of late been almost exclusively of the rotary, mainly screw (or centrifugal for large outputs) type. This is because piston compressors, although having higher efficiencies during compression, but more especially during unloaded running, need much more maintenance. One area of such maintenance is the valves. Valves on practical compressors are always air pressure operated steel diaphragm types, with harsh mechanical opening and closing characteristics, with the dynamics of the movements of the mechanical elements being largely uncontrolled. The stress and wear of the valves which this gives rise to is the main reason for having to change valves frequently.

In order to make piston type compressors, with all their intrinsic advantages again competitive, it is proposed (in one

aspect of the invention) to replace the pressure operated valves with controlled motion valves, such as are used, for example, on most heat engines, whether internal combustion or steam.

In the operation of a positive displacement type of air compressor, a piston is driven back and forth within a cylinder at relatively low speed, and inlet and outlet valves are operated in timed sequence with the movement of the piston so as to control (1) the induction of a charge of air (2) compression of the charge and (3) discharge of the compressed charge in a repeated cycle of operations.

The inlet valve is normally held open throughout the major part of the induction stroke of the piston, and is held closed against its valve seat during the compression and discharge stroke of the piston, whereas the exhaust valve is normally held closed against its valve seat during the induction stroke and also the major part of the compression stroke, and is only held open for a short time interval at or near the end of the compression stroke to allow the compressed charge to be discharged.

Usually, positive displacement compressors are of the double acting type, so that each side of the piston can carry out its own cycle of operation with respect to the air chamber defined within the cylinder between that piston side and the facing end of the cylinder, and corresponding inlet and outlet valves are provided to control the air chambers defined on each side of the piston.

Each valve is movable towards and away from the respective valve seat as it moves between the open and closed position, and in some applications it is desirable to provide some form of resiliently deformable seal which is engaged by the valve as it moves to the closed position. In order for the seal to have a useful life, it is desirable to provide some means of actuation of each valve which minimises the impact of the closing force of the valve on the respective seal.

It is known, in the actuation of inlet and exhaust valves of internal combustion engines, to apply a direct mechanical

force to the upper end of a valve stem to move the respective valve against spring pressure away from the closed position to the open position, and then upon removal of the actuation force to allow the valve to return to its closed position under spring pressure. However, this known arrangement is not believed to be suitable to provide a desired objective of one aspect of the invention, namely closing movement of a valve which reduces in speed as the valve approaches and then reaches its closed position against its valve seat.

In this one aspect of the present invention, this is particularly beneficial for a preferred type of cylinder valve in which an O-ring type seal is provided, but it should be understood clearly that the invention is not restricted to such use, and will give advantages of wear reduction with many other types of valve seat.

Accordingly, in one aspect of the invention, there is provided a hydraulic actuator for a cylinder valve and which comprises:

a cyclic hydraulic flow generator for producing repeated cycles of hydraulic flow output in which each cycle has an oscillating waveform;

a master circuit communicable with said generator;

a slave circuit communicable with said master circuit;

a valve operator communicable with said slave circuit and connectable to a cylinder valve, said operator being operable in a release mode to move the valve away from its valve seat and in a valve-closing mode to move the valve towards its valve seat; and,

valve means for controlling the flow of hydraulic fluid in the master circuit and the slave circuit and operable at predetermined time intervals within each cycle of operation of the generator in order to apply selected samples of the oscillating waveform of the generator output to operate the valve operator in both modes of operation.

When, as is preferred, there is a requirement for a valve closing speed which reduces as the valve approaches and then engages its valve seat, the selected sample of the oscillating

waveform of the generator output will be taken from a portion of the waveform in which the flow is reducing i.e. in a phase of the waveform between a peak and a succeeding trough.

In a positive displacement compressor, which for preference is provided with soft seals, and packings for the inlet and exhaust valves, it can therefore be arranged that each valve makes a relatively gentle engagement with its seal as it completes its closing movement, and this will enhance the working life of such seals and reduce maintenance costs.

The invention is not, however, restricted to use either in a positive displacement type compressor having soft seals, or indeed in a positive displacement compressor as such, but has general application to hydraulic actuation of cylinder valves of other types of engine (pumps or motors) having valve controlled fluid pressure chambers which are filled, pressurised and then discharge pressure fluid in repeated cycles of operation.

According to a second aspect of the invention, there is provided a hydraulically actuated cylinder valve which comprises:

a valve seat;

a linearly reciprocable valve element movable between open and closed positions with respect to the valve seat;

a valve seal arranged to seal the valve element with respect to the valve seat, when the valve element is in the closed position;

a valve operator connected to the valve element and operable in a release mode to move the valve element away from its valve seat and in a valve-closing mode to move the valve element towards its valve seat; and,

a hydraulic actuator circuit communicable with said valve operator and operable to apply a closing motion to the valve element via the valve operator which reduces in speed as the valve element moves towards the valve seat and engages with the valve seal.

Preferably, the valve seal comprises a resiliently deformable seal which may be an O-ring or other soft packing,

and which may be housed in the closing face of the valve element, or in the portion of the valve seat engageable by a head of the valve element.

According to a third aspect of the invention there is provided a linearly reciprocating piston type compressor which comprises a cylinder, a floating piston mounted for linear reciprocation in said cylinder, a piston rod coupled with said piston and guided so as to control the reciprocating movement of the piston in said cylinder so as to be substantially without direct metal to metal contact with the internal wall of the cylinder, at least one cylinder valve for controlling the admission, or exhaust, of gas relative to the cylinder, a valve seat co-operable with said cylinder valve, and an actuator coupled with said cylinder valve and operable to move the valve towards its valve seat, in sequence with the reciprocation of the piston, and with a speed which reduces as the valve approaches and then engages the valve seat.

A preferred embodiment of the invention will now be described in detail, by way of example only, with reference to the accompanying drawings in which:

Figure 1 is a schematic illustration of a hydraulic actuator circuit for a cylinder valve according to the invention;

Figure 1a is a detail of an alternative arrangement of part of the circuit shown in Figure 1;

Figure 2 is a series of graphs showing the operating cycles of the component parts of the circuit shown in Figure 1; and,

Figure 3 is a schematic illustration of a further circuit arrangement according to the invention.

Referring now to Figure 1 of the drawings, there will be described a preferred embodiment of the invention in relation to the control of the opening and closing movements of inlet and exhaust valves of a positive displacement type air compressor, by way of example only. The actuator circuit is particularly suitable for use with a positive displacement type compressor having a "floating piston", and provided with soft

seals or packings to seal the valves when in the closed positions. (A "floating piston" type of compressor is one in which the piston does not engage the internal wall of the cylinder by direct metal to metal contact, and does not have any piston rings, but has its reciprocating movement guided so that there is a small radial clearance between the cylinder wall and the periphery of the piston. The absence of frictional contact between piston and cylinder contributes to a long service life of the compressor, and to low maintenance, as there is no wear and there are no piston seals which require routine inspections and replacement when necessary.

Figure 1 shows a hydraulic actuator circuit for a single cylinder valve, which can be the inlet valve or the exhaust valve, and Figure 2 shows cycles of operation of the inlet and exhaust valves.

The hydraulic actuator shown in Figure 1 is intended to operate a cylinder valve, shown schematically by reference 10, and which comprises a valve seat 11, and a valve element 12 which is linearly reciprocable between open and closed positions with respect to valve seat 11, element 12 having a valve head 13 which is engageable with valve seat 11 when in the closed position. Although not shown, preferably a resiliently deformable valve seal is provided, which may take the form of an O-ring or soft packing, and which is housed either in the closing face of head 13, or in a part of the valve seat 11 engaged by the head 13.

The hydraulic actuator, which controls the linear reciprocation of valve element 12, will now be described in detail. The actuator comprises a cyclic hydraulic motion generator for producing repeated cycles of hydraulic flow output having an oscillating waveform, and in the schematic illustration comprises a master cylinder 14 having a piston 15 which is driven back and forth within cylinder 14 under the action of a rotary crank mechanism 16. The crank mechanism 16 will rotate in a proportional relationship to the operation of the cylinder whose valves are to be controlled, so that the inlet and exhaust valves can be operated at required time

intervals during the induction, compression and exhaust stages of the air compressor.

Each cycle of operation of the hydraulic flow generator has an integral number of peaks and troughs per compressor cycle, and in the illustrated arrangement has six peaks and troughs of a sinusoidal waveform, as can be seen at graphs b and c in Figure 2.

Graph 2a shows a graph of movement of piston 17 of compressor cylinder 18 and the selected intervals of operation of the inlet and exhaust valves during each cycle of operation of the compressor.

The master cylinder 14 of the cyclic motion generator is communicable with a master circuit 19 having flow and return lines which communicate with opposite ends of the master cylinder 14, and which include a valve-controlled bridging line 20 provided with a diverter valve 21 whose operation between open and closed positions is controlled as part of the operating sequence of the hydraulic actuator, as will be discussed in more detail below.

A slave circuit 22 is communicable with master circuit 19, and is connected to opposite ends of a slave cylinder 23 having actuator piston 24 coupled with the valve stem of valve element 12, and which thereby forms a valve operator which is operable in a release mode to move the valve element 12 away from valve seat 11, and in a valve-closing mode to move the valve element 12 towards the valve seat 11.

Slave circuit 22, together with diverter valve 21 in master circuit 19, forms jointly a "valve means" for controlling the flow of hydraulic fluid in the master circuit 19 and the slave circuit 22 and operable at predetermined time intervals within each cycle of operation of the motion generator (master cylinder 14) in order to apply selected samples of the oscillating waveform of the generator output to operate the valve operator (23, 24) in both modes of operation.

The operation of the valve means (21) is controlled in such a way that the closing speed applied to the stem of the valve element 12 reduces as the head 13 approaches and then

moves into engagement with the valve seat 11 i.e. at or near the end of the closing stroke of movement. This minimises valve seat and valve wear (which may be direct metal to metal contact), and in the case of use of resiliently deformable seals and soft packings, enhances seal life, and therefore reduces maintenance costs.

When the suction valve, for instance (for maintenance, unloading or safety purposes) is on the outside, then a discrete force to resist the air pressure is needed during the compression strokes. Similarly, the exhaust valve amy also need locking down if premature opening is not desired.

Therefore, while the master circuit 19 and slave circuit 22, under control of the valve 21, and also of control valve 25, provide controlled application of selected portions only of the oscillating waveform produced by the master cylinder 14, in order to move the valve element 12 towards and away from the closed position, preferably a separate hydraulic pressure device is provided to maintain the valve element "locked" in the closed position when it has been moved to that position. Therefore, a high pressure source 26 is provided which is communicable with the slave circuit 22 via control valve 27, to apply a constant biasing force to piston 24 after the latter has been moved to the left upon completion of a closing movement under the control of valves 21 and 25 of the master circuit 19 and slave circuit 22. The sequence of operation of valves 21, 25 and 27, for a typical cycle of operation will be described in more detail below.

Assuming that the valve element 12 is the inlet or suction valve, Figure 2b shows the oscillating waveform produced by the suction valve master cylinder, and Figure 2a shows the time intervals, during a cycle of operation, in which the suction valve carries out opening movement, as shown by the relatively short section 28 of the graph, and by longer section 29 in which the valve is maintained open (preferably by means of a small spring biasing force), followed by short section 30 in which valve closing movement takes place, followed by further longer section 31 in which the valve remains closed.

Figure 2b shows the oscillating waveform of the suction valve master cylinder, and the two marked samples of this waveform, shown by references 32 comprise short duration predetermined time intervals at which diverter valve 21 is closed, in order to initiate suction valve opening at section 28 and suction valve closing shown by reference 30 in Figure 2a.

While the diverter valve is open, the suction valve dwells (either closed or open) along lines 39 and 40 while the waveforms are being short-circuited or by-passed.

Figure 2c shows the oscillating (sinusoidal) waveform generated by the exhaust valve master, and very short predetermined selected sample of this waveform shown by reference 33 is the interval at which the diverter valve 21 of the exhaust valve master circuit is closed, it being understood that inlet valve master circuit has its own diverter valve 21 operated at predetermined short term intervals 32 described above with reference to Figure 2b.

Upon closure of the diverter valve associated with the exhaust valve at section 33, the exhaust valve is caused to open and close at the final portion of the compression stroke of piston 17 to allow the compressed charge of air to be discharged, this final section being shown by reference 34 in Figure 2a.

As can be seen from Figure 2b, in respect of the second predetermined interval 32 at which the diverter valve (21) associated with the inlet master circuit is operated, the inlet master waveform is moving from the peak value shown by reference 35 to the succeeding trough shown by reference 36, and therefore the closing speed applied to valve element 12 will reduce as it approaches and then moves into engagement with the valve seat 11.

Similarly, the closing speed applied to the exhaust valve also takes place while the exhaust master waveform is moving from peak 37 to trough 38 shown in Figure 2c.

There will now be described typical cycle of operation in respect of either valve element:

1. With the control valve 25 of slave circuit 22 open, and control valve 27 closed, the following operations can take place:

(a) with the diverter valve 21 closed, the sleeve 23 (or piston 24) reciprocates to move the valve element 12;

(b) with the diverter valve 21 open, fluid in the master circuit 19 "short circuits" or bypasses the slave circuit 22, whereby the valve element remains at rest.

2. With the diverter valve 21 open, the control valve 25 closed, and control valve 27 open;

the valve element is held pressed to the left against the valve seat 11, so that the air valve cannot open.

The diverter valve 21 is only closed when valve 25 is open and control valve 27 closed, so that the sleeve (or piston) can move. The high pressure from source 26 is used to keep the suction air valve closed during the compression stroke when, as is preferred, the air valve is located on top of the cylinder end plate which is convenient for some applications.

The master circuit and slave circuit described so far with reference to Figure 1 will be provided with replenishment lines and pressure relief lines, as shown schematically by reference 40 and 41 for the replenishment lines and relief lines respectively, and coupled with the master circuit 19m, and operating in a manner which will be well known to those of ordinary skill in the art.

Figure 1 provides an arrangement for controlling the movement of actuator sleeve 23 and its piston 24, and an alternative arrangement for diverter valve 21 is shown in Figure 1a. Here, also, the selected waveform is transmitted directly through the valve, while the unwanted waveforms are short-circuited, as in valve A of Figure 1. However, while the master waveforms are being short circuited, the sleeve circuit is locked in position; rather than being free to move as would be possible in the case of valve A in the Figure 1 arrangement.

In both cases, i.e. Figure 1 and Figure 1a, if either valve A is permanently open, or the valve of Figure 1a is in position a, circuit 13 is free to move when acted on by

external forces and can then be unloaded if e.g. biasing spring S is applied.

If it may be desired to vary the period of the waveform 37 which is generated by the rotary crank mechanism 16, a variable differential drive input may be provided, which enables variation in the sampled waveform.

The control valves which are illustrated schematically will preferably be electrically control valves e.g. solenoid valves.

Finally, an alternative circuit arrangement according to the invention is shown in Figure 3, and in which parts corresponding with those already described are given the same reference numerals. This is a "piggyback" type of arrangement, in which a double piston rod type of actuator has piston rods 1 and 2 of the same diameter. This is necessary, because otherwise short circuiting would not be possible, in that it would be self-locking. This actuator is attached to valve element 13 to be pulled by it.

An objective of this arrangement is to avoid absorbing an unacceptable amount of energy, and in particular to avoid drawing on a 1,000 psi oil supply. To achieve this, the locking piston must travel forwards (to the left in the drawing). Then, when the locking pressure is switched on, it must not allow any more fluid than the compressibility of the fluid in volume 3 allows.

If there were to be locking on area directly, as per the previous examples, then because area 4 has to be small to allow free oil flow in circuit line 19, a very high pressure would be needed, and which would result in unacceptable leakage and compression energy loss. However, the piggyback arrangement shown in Figure 3 overcomes this problems.

CLAIMS

1. A hydraulic actuator for a cylinder valve and which comprises:

a cyclic hydraulic flow generator for producing repeated cycles of hydraulic flow output in which each cycle has an oscillating waveform;

a master circuit communicable with said generator;

a slave circuit communicable with said master circuit;

a valve operator communicable with said slave circuit and connectable to a cylinder valve, said operator being operable in a release mode to move the valve away from its valve seat and in a valve-closing mode to move the valve towards its valve seat; and,

valve means for controlling the flow of hydraulic fluid in the master circuit and the slave circuit and operable at predetermined time intervals within each cycle of operation of the generator in order to apply selected samples of the oscillating waveform of the generator output to operate the valve operator in both modes of operation.

2. An actuator according to Claim 1, and adapted for a cylinder valve having a requirement for a valve closing speed which reduces as the valve approaches and then engages its valve seat, the arrangement being such that the selected sample of the oscillating waveform of the generator output can be taken from a portion of the waveform in which the flow of hydraulic fluid is reducing at or near the maxima or minima of the waveform.

3. A positive displacement compressor having an actuator according to Claim 2, in which the actuator is arranged to operate its respective valve such that the valve makes a relatively gentle engagement with its seal as it completes its closing movement.

4. A compressor according to Claim 3, and having a floating piston guided to reciprocate within a cylinder other than by engagement with the internal wall of the cylinder.

5. A hydraulically actuated cylinder valve which

comprises:

a valve seat;

a linearly reciprocable valve element movable between open and closed positions with respect to the valve seat;

a valve seal arranged to seal the valve element with respect to the valve seat, when the valve element is in the closed position;

a valve operator connected to the valve element and operable in a release mode to move the valve element away from its valve seat and in a valve-closing mode to move the valve element towards its valve seat; and,

a hydraulic actuator circuit communicable with said valve operator and operable to apply a closing motion to the valve element via the valve operator which reduces in speed as the valve element moves towards the valve seat and engages with the valve seal.

6. A cylinder valve according to Claim 5, in which the valve seal comprises a resiliently deformable seal housed in the closing face of the valve element, or in a portion of the valve seat engageable by a head of the valve element.

7. A cylinder valve according to Claim 6, in which the resiliently deformable seal comprises an O-ring or other soft packing.

8. A linearly reciprocating piston type compressor which comprises a cylinder, a piston mounted for linear reciprocation in said cylinder, at least one cylinder valve for controlling the admission, or exhaust, of gas relative to the cylinder, a valve seat co-operable with said cylinder valve, and an actuator coupled with said cylinder valve and operable to move the valve towards its valve seat, in sequence with the reciprocation of the piston, and with a speed which reduces as the valve approaches and then engages the valve seat.

9. A compressor according to Claim 8, in which the actuator comprises a hydraulic actuator.

10. A compressor according to Claim 9, in which the hydraulic actuator comprises a cycle hydraulic flow generator for producing repeated cycles of hydraulic flow output in which

each cycle has an oscillating waveform; a mater circuit communicable with said generator; a slave circuit communicable with said master circuit; a valve operator communicable with said valve circuit and connectable to said cylinder valve, said operator being operable in a release mode to move the valve away from its valve seat and in a valve-closing mode to move the valve towards its valve seat; and valve means for controlling the flow of hydraulic fluid in the master circuit and the slave circuit and operable at predetermined time intervals within each cycle of operation of the generator in order to apply selected samples of the oscillating waveform of the generator output to operate the valve operator in both modes of operation.

11. A compressor according to any one of Claims 8 to 10, in which the piston is a floating piston, and a piston rod is coupled with said piston and is guided so as to control the reciprocating movement of the piston in said cylinder so as to be substantially without direct metal to metal contact with the internal wall of the cylinder.

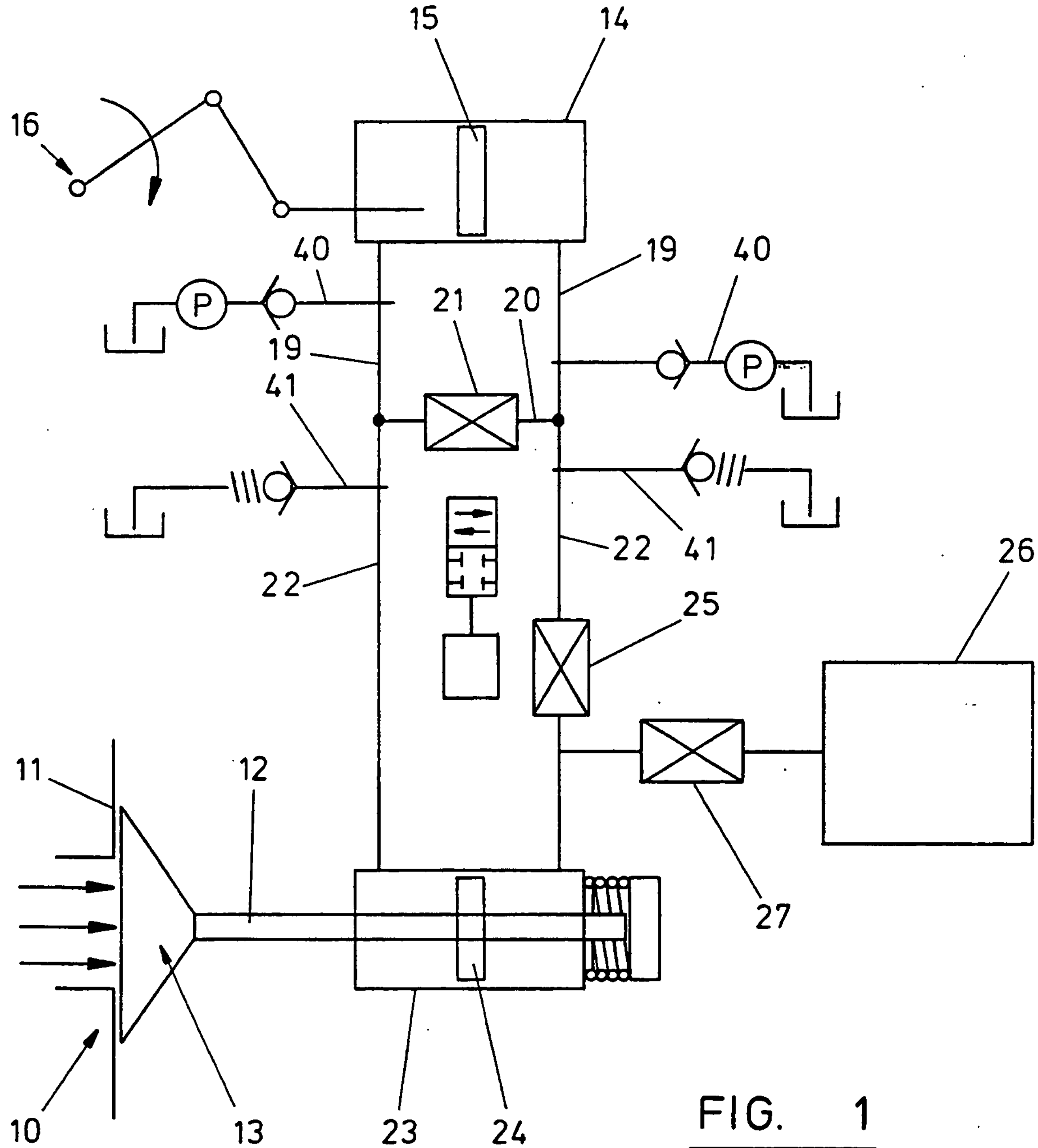
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FIG. 1

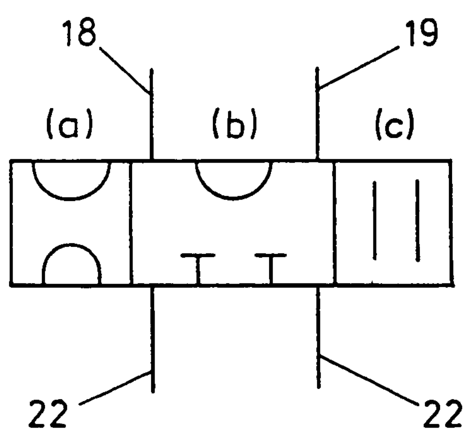
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FIG. 1a

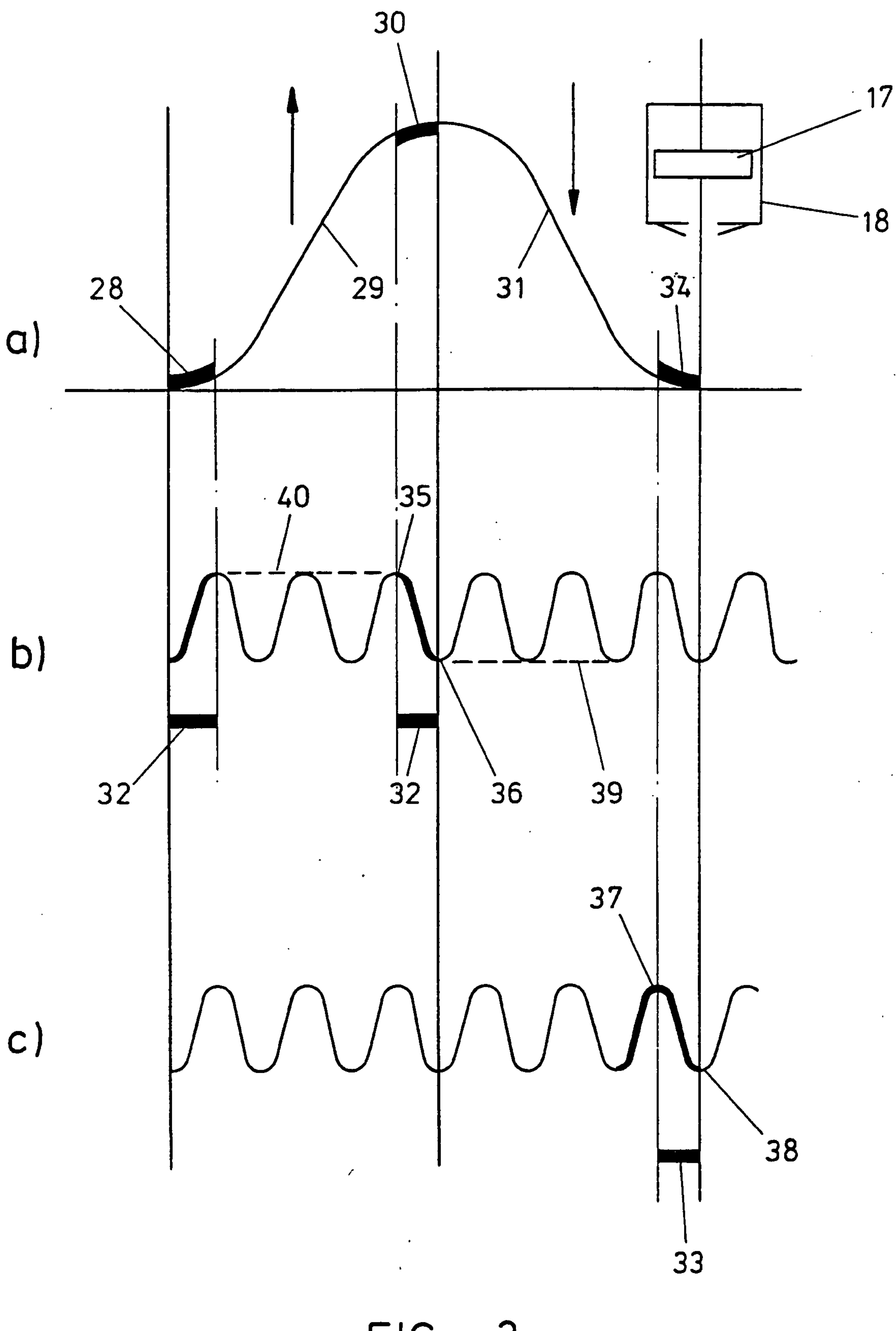

FIG. 2

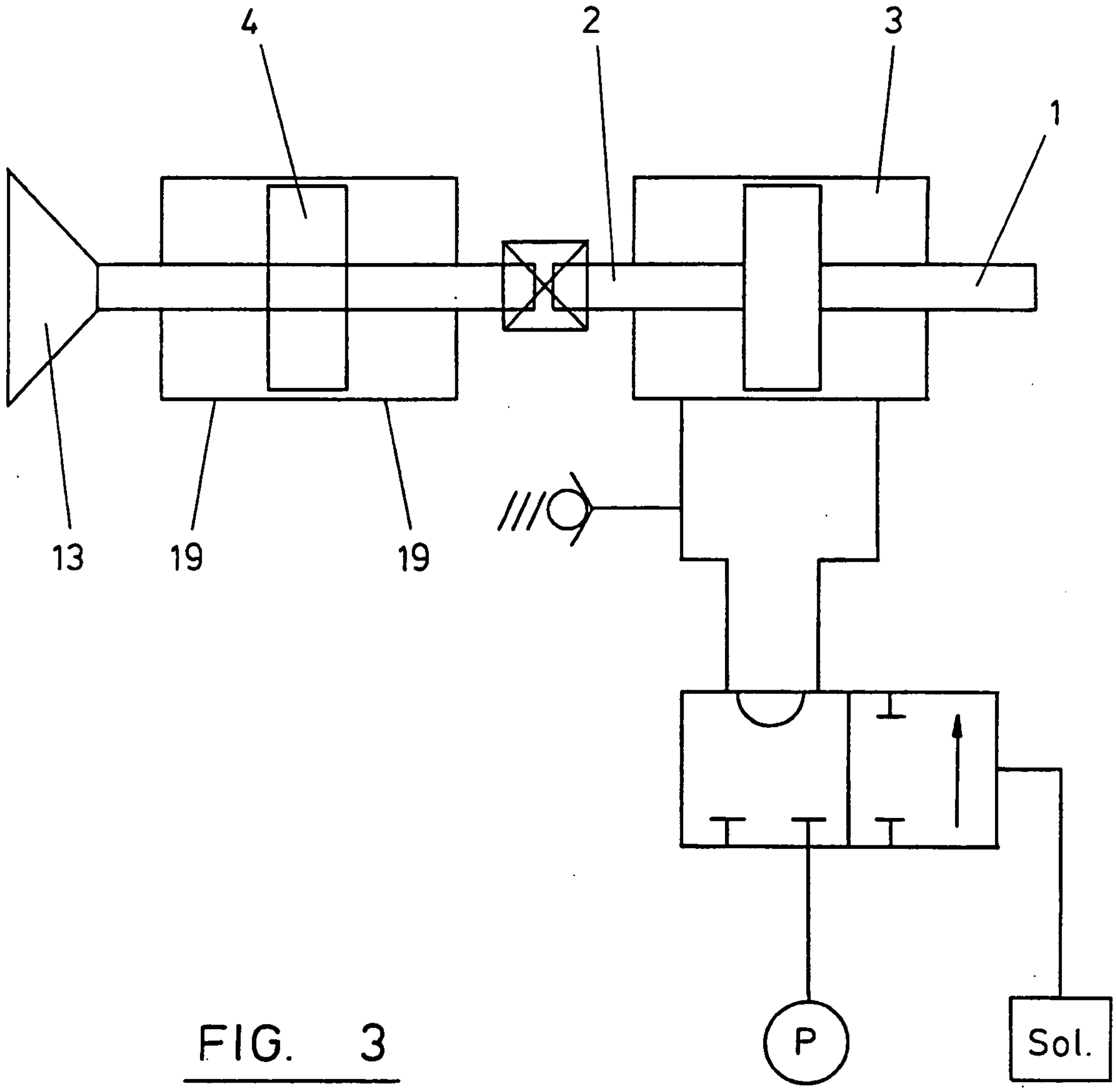

FIG. 3

INTERNATIONAL SEARCH REPORT

International Application No
PCT/GB 94/01598

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 F04B7/02 F01L9/02 F04B39/08

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 F04B F01L

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US,A,2 135 247 (AIKMAN) 30 August 1984 see claims 1,2; figures ---	1,5,8
A	EP,A,0 391 507 (MITSUBISHI) 10 October 1990 see abstract; figures ---	1,2,5
A	PATENT ABSTRACTS OF JAPAN vol. 10, no. 126 (M-477) 10 May 1986 & JP,A,60 252 113 (MASAFUMI) 12 December 1985 see abstract -----	1

☐ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
12 October 1994	26.10.94

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INTERNATIONAL SEARCH REPORT

Information on patent family members

Inte. .onal Application No
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Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US-A-2135247		NONE	
EP-A-0391507	10-10-90	DE-D- 69009097	30-06-94
		DE-T- 69009097	01-09-94